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Flight Validation of On-Demand Operations: The Deep Space One Beacon Monitor Operations Experiment

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Reducing the frequency of routine telemetry contact is essential for reducing the cost of missions with long duration cruise phases. Supporting the many more planned NASA missions is also a major concern of the **Telecommunications and Mission Operations Directorate at** JPL which plans for utilization of the Deep Space Network antennas. An operational concept called Beacon Monitor Operations was conceived for use on Pluto, Europa, and other planned NASA missions and has been developed over the last two and one half years for flight demonstration on the Deep Space One mission. The basic concept is that the spacecraft initiates **telemetry** contact only when required by instead routinely sending a beacon tone (a modulated subcarrier signal) to indicate the urgency of ground intervention. If contact is required, the spacecraft sends telemetry that the spacecraft has autonomously summarized onboard. If no contact is required, the tone provides ground personnel with regular assurances that mission is proceeding as planned. Software

When an event requiring ground action occurs, tone selection software maps spacecraft health status messages to tone state and changes the transmitted tone from _All OK_ to one of the three more urgent tone states. The tone is then transmitted to earth where small aperture antennas conduct short passes to periodically poll the spacecraft. Although this mapping of spacecraft state to tone state is relatively straightforward, an ideal beacon mission would also leverage the enhanced state determination capability provided by onboard summarization technology.

Summarization algorithms are intended to provide operators with all of the necessary telemetry when the spacecraft has determined that ground intervention is required. Several summarization techniques have been combined into one set of algorithms for flight validation on DS1. One technology component consists of a set of transforms on engineering data. These transforms have a heritage in AI research performed at JPL in the area of selective monitoring. These act as pseudo onboard sensors, implementing empirical transforms that can be defined and uploaded easily during the mission. The current transforms for DS1 are running high, low, and average values, first derivative, and second derivative. Alarm limits can also be placed on transform data to improve the overall anomaly detection capability.

The summarization architecture also uses a JPL-developed method for creating alarm limit functions that are learned using a neural network. This technology component, called ELMER (Envelope Learning and Monitoring using Error Relaxation), replaces traditional red-lines with adaptive alarm thresholds to provide faster detection with fewer false alarms. Training can be performed onboard or on the ground (DS1 uses ground-based training). ELMER is particularly powerful because very little knowledge engineering is required and training of the neural net is accomplished using nominal data.

The summarization algorithms produce four types of engineering telemetry and are queued for downlink using a priority-driven onboard telemetry manager. The first component of the summary contains high-level spacecraft information, such as the number of alarm crossings, spacecraft mode and state histories, and other pertinent statistics since the last ground contact. Episode data is gathered for the culprit and causally related sensor channels whenever a sensor violates its alarm threshold. Episode data is stored at a high sample rate since it is of high-value to ground operators. Snapshot telemetry is a sample of all sensor and transform channels at one time-slice and is collected at a much lower sample rate. Snapshot data is used only for rough correlations and to fill in the gaps between episodes. The last component of the downlinked summary is called Performance Data This is similar to episode data but captures maneuvers or other events where it is known in advance that the data will be of interest to people on the ground. All of the summary algorithms are implemented in C for the VxWorks operating system. This is the most comprehensive onboard summarization system to fly on a JPL mission. Once validated, it will be available for full-up mission use during the remainder of the DS1 prime mission and may turn out to be an important enabler for the extended mission.

Flight validation for DS1 will proceed in three phases. The first phase consists of an initial functional checkout of the system. The next phase is validation of the tone and summarization systems. The third phase is when the entire end-to-end process will be demonstrated. The cost savings due to decreased antenna demand and operations staffing reductions will be evaluated through parallel operations experiments. Once validated, the tone and summarization systems will be available for mission use.

After a brief overview of the operational concept, this paper will provide a detailed description of the _as-flown_ flight software components, the DS1 experiment plan, and experiment results to date. Special emphasis will be given to experiment results and lessons learned since the basic system design has been previously reported. Mission scenarios where beacon operations is highly applicable will be described. Detailed cost savings estimates for a sample science mission will be provided as will cumulative savings that are possible over the next fifteen years of NASA missions.